Advanced imaging and relative navigation technology for Human and Robotic Servicing of Space Systems

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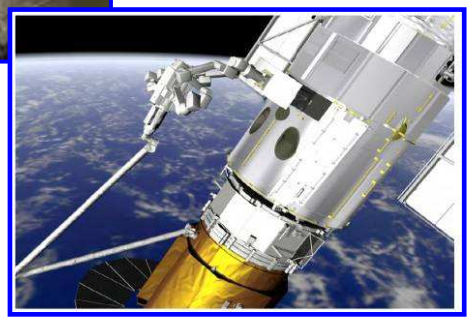
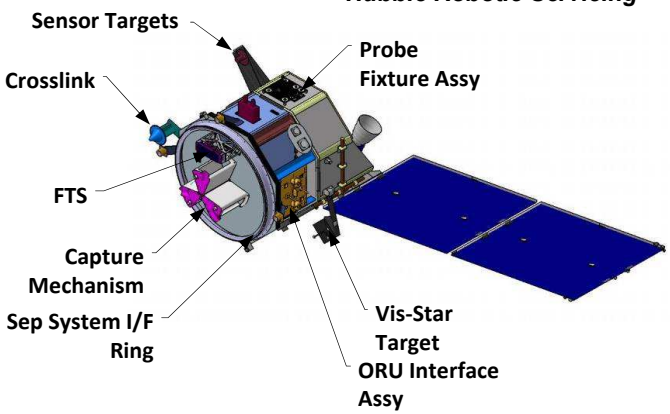
Key examples of human and robotic on orbit satellite servicing

- **Hubble servicing**
  - Fabrication of precision optical instruments, including analysis of all key performance properties related to optics, mechanics, mechanisms, thermal, electrical, electronic and others
  - Astronaut Training Support
  - Precision test facilities to assure instrument compatibility with the observatory
- **Significant role in the design of Hubble Robotic Servicing and De-orbit Mission**
  - Robotic servicing of Hubble
- **Developed NEXTSat spacecraft for Orbital Express**
  - The mission proved in space replacement of components (batteries and computer) and re-fueling
- **Shuttle hardware development, production and maintenance**
- **Broad participation and support of NASA servicing community**

Wide Field Camera 3, Delivered for HST SM-4



Hubble Robotic Servicing



Orbital Express: Ball NextSat Vehicle

Challenges of in-space assembly and servicing are non-trivial

- Contamination control around high value assets, including optical systems
- Servicing after potentially years of in space environments
- Servicing systems that may/may not have been designed for servicing
- Providing Imaging and Relative Navigation solutions are some of the most critical challenges

Crew Training for ACS Repair Electronics on HST SM-4

A. Feustel Installs Wide Field Camera 3 on HST SM-4

Servicing functionality drives technology

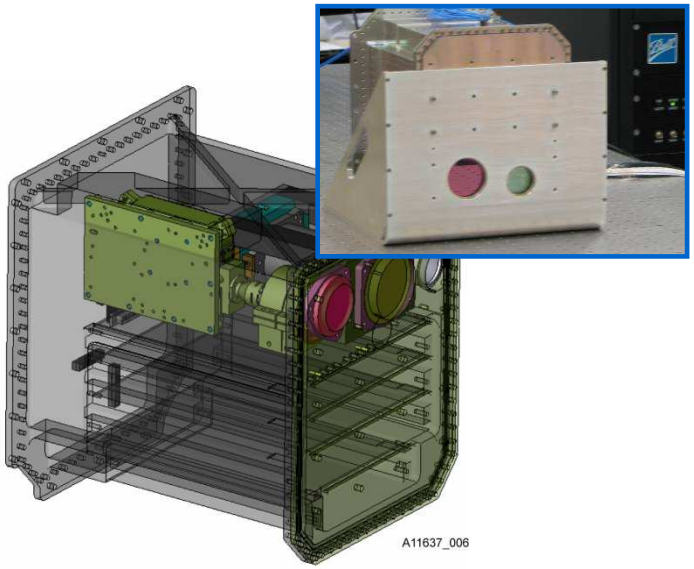
- **Functional Objectives**
  - Autonomous Rendezvous, Proximity Operations and Docking (ARPOD)
  - Robotic and telerobotic Inspection and Servicing
- **Key Characteristics**
  - ARPOD
    - Large Dynamic Range Ensures Safety from Initial Acquisition through Docking
    - Common Interface Standards
    - Operates in all Lighting Conditions
      - Scene insensitive: Farfield and nearfield effects, including glint
    - Explicit Range Measurement
    - Accommodate wide range of approach trajectories
      - Wide angle
      - Fully correlated imaging
    - Relative State Estimation: cm class knowledge
  - Inspection/servicing
    - High resolution imaging to complement LIDAR data set
    - Video frame rates
    - Jitter tolerance
    - Unambiguous locating of features in servicer relative frame
    - All lighting conditions
    - Relative State Estimation: mm class knowledge

Critical Robotic Imaging and RelNav Technologies

- **3D Nav and Situational Awareness**
  - 5 km to docking
  - 3 dof and 6 dof navigation data at video rate
  - All lighting solution
  - Full frame imagery
  - High resolution
- **Real time high performance algorithms**
  - Feature identification
  - Nav processing
  - Multi-sensor fusion
- **Line of Sight Control**
  - Vibration Rejection
  - Disturbance Reduction

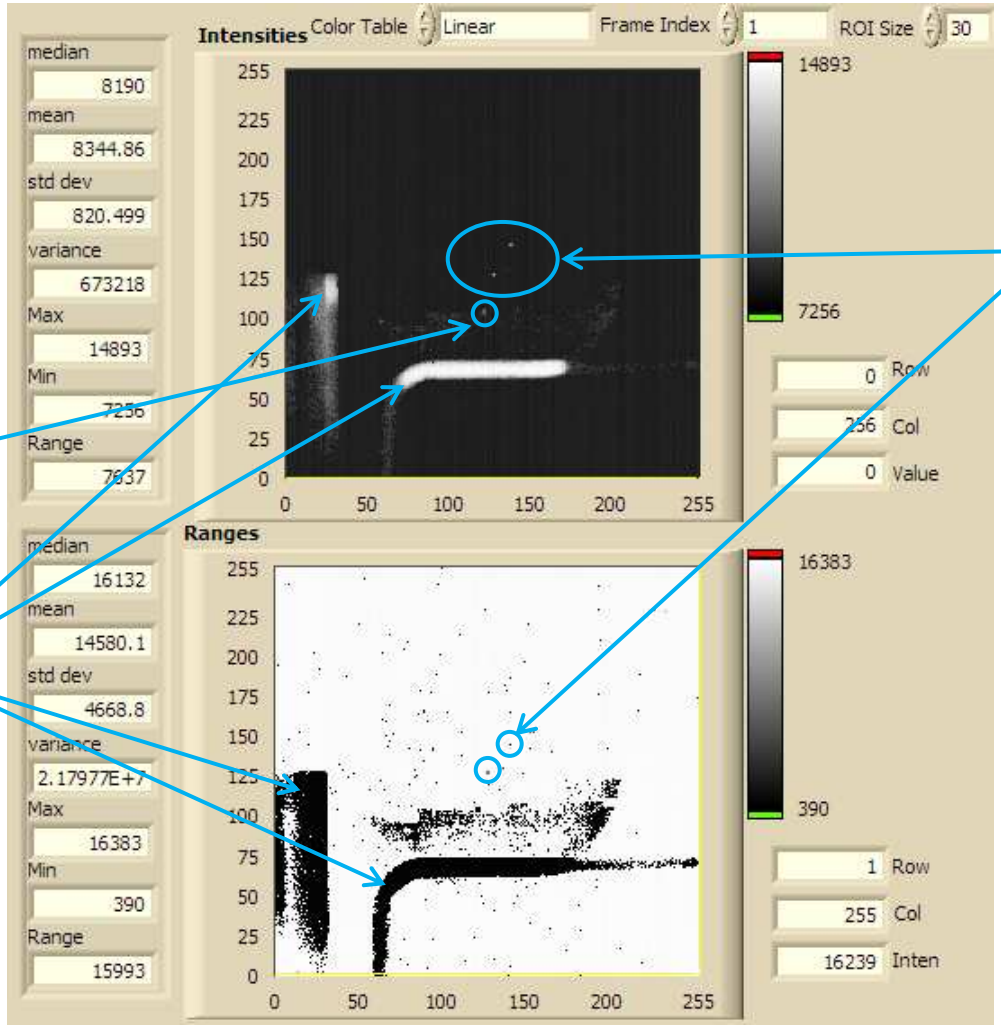
Pointing Systems Provide Broad Field of Regard to Imaging Systems

Advanced Isolation and Disturbance Reduction Such as that Used in WorldView2 Required to Stabilize Vision and Manipulator Systems



Commercial Navigation Sensor System Fuses High Res Imager and LIDAR

State of the Art 3D Imaging:
Orion Vision Navigation Sensor Long Range Test



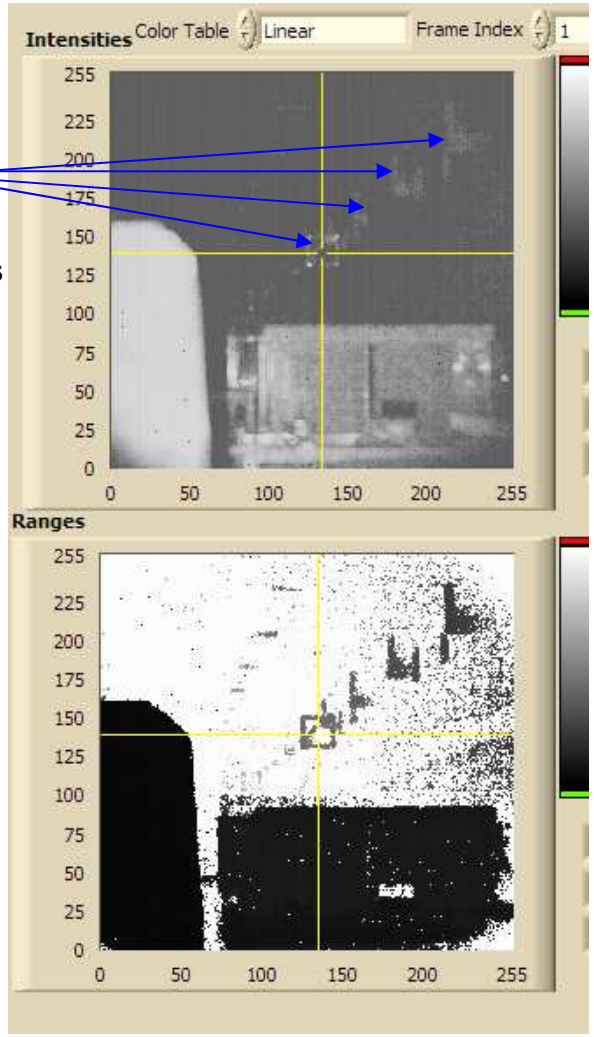
Retroreflectors

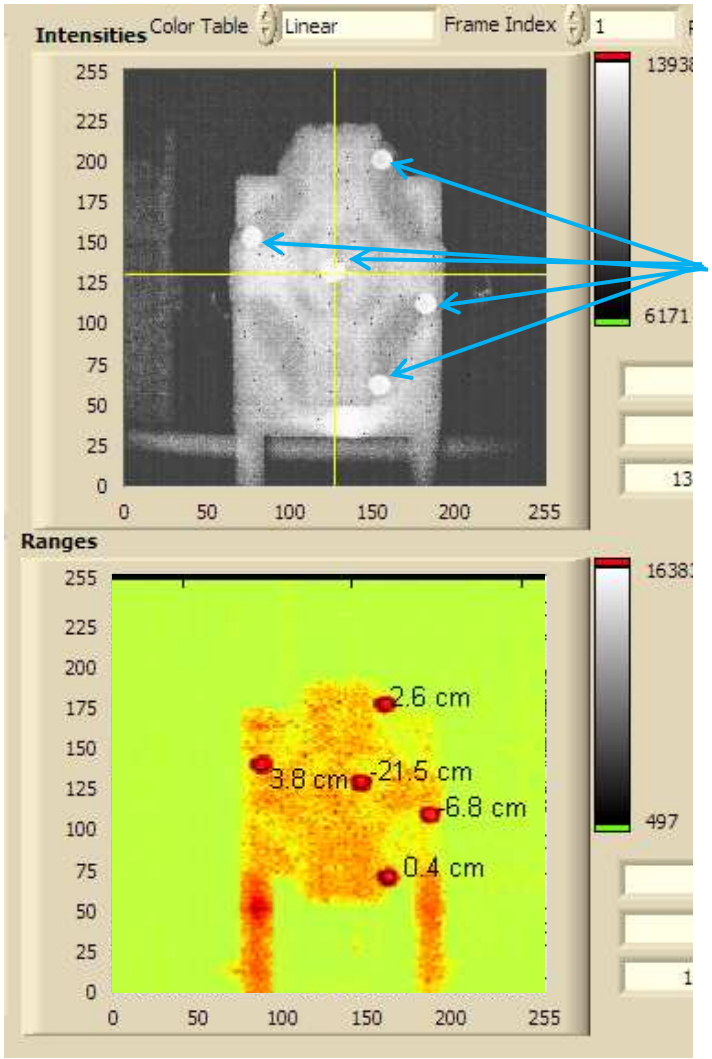
No Parking sign on building at range of approximately 200 m.

Railing and other structure on edge of roof top lab at range of approximately 4 m.

VNS Mid-Short Range Tests

Intensity response from multiple target sets at varying ranges illustrates unambiguous feature ID





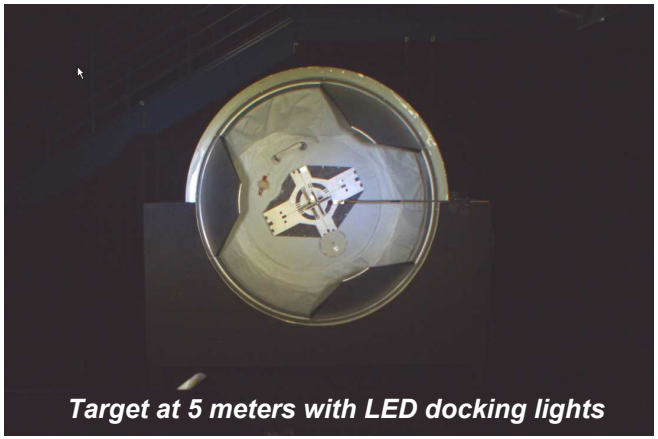
Intensity response from short range reflectors provides bearing to targets

Short Range Flash LIDAR "Docking" Movie

High Resolution Space Camera

Characteristic	Orion Docking Camera	Camera Variants
Color	Bayer pattern color sensor	Monochrome or color
Dynamic Range	12 bits	
Frame Size (Resolution)	Commandable Up to 2592 x 1944 (5MP)	Any frame format up to 2592 x 1944 is available
Frame Rate (Hz)	15 @ 5.0 MPixel, 60 @ 1.3 MPixel	
Integration time / Exposure	Automatic or Commandable	Same
Sun in the FOV	Undamaged, no blooming	Same
Weight (lb)	1.7	
Power (W)	3.1	
Telemetry Interface	RS-422	
Data I/F	Channel Link LVDS (UT54LVDS217)	Variants of CameraLink

Highly flexible space camera applies advanced CMOS and FPGA technology

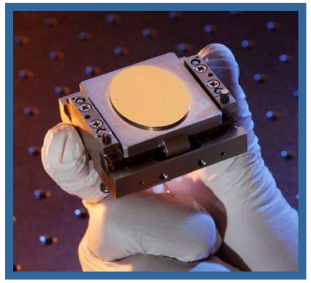


Target at 5 meters with LED docking lights

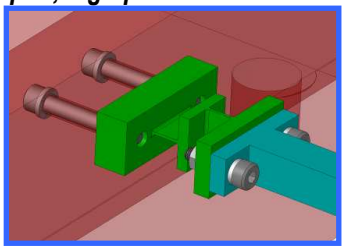
Critical Technologies: Line of Sight Control

- Pointing, Jitter Isolation and Vibration management are enabling for in space servicing because servicing system:
  - Requires broad fields of regard
  - Is (typically) susceptible to gravitational disturbances, on-board vibration noise sources, and structural dynamics
- Active solutions for pointing control with low frequency/large amplitude dynamics and vibration, include:
  - Gimbal systems
  - Fast steering mirrors
- Advanced gimbal systems provide large range of travel, but may also provide base motion compensation
- Fast steering mirrors have been used for very high precision control, such as beam steering for very long range point-to-point laser communications
- Passive solutions, normally applicable for isolation with high frequency noise sources, include use of flexures, viscoelastic mounting, etc.

SBSS



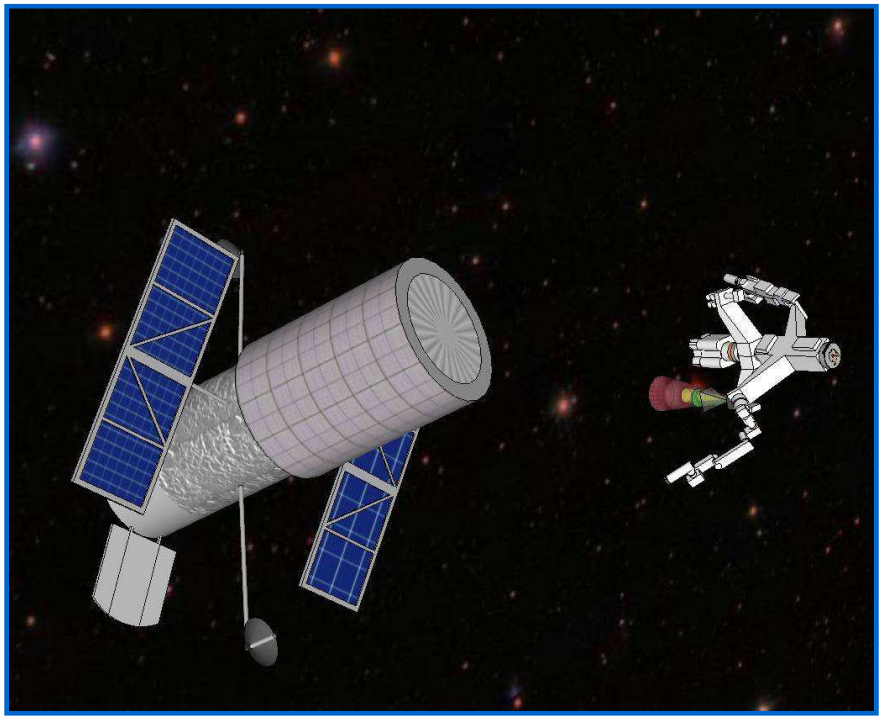
Fast steering mirror
Small optic, high power reflective coating



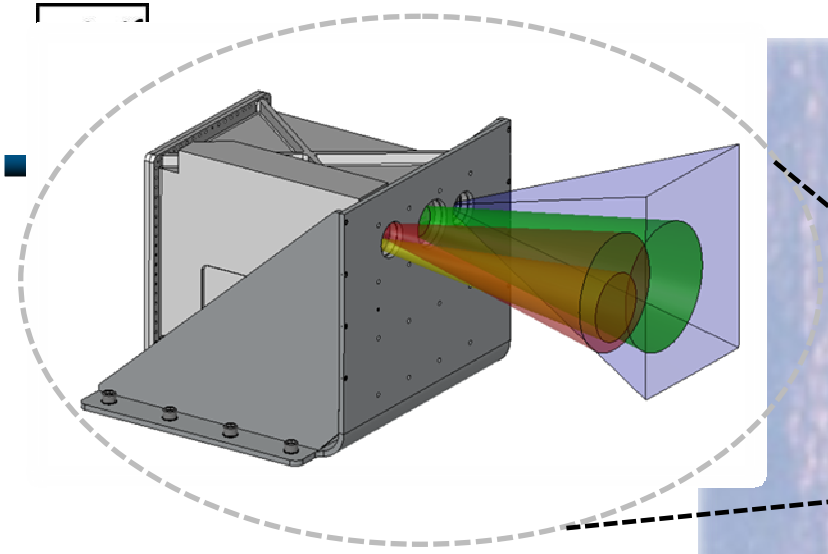
Passive isolation solutions

Conclusions, Related Applications and Future Development

- **Critical Technologies for Satellite Servicing Are Now Mature**
- **Many Other Applications Benefit from the Same Imaging Technology**
  - Space Tug Autonomous Rendezvous
  - ISS "Harbor Master": Safety watch for incoming vehicles from semi-permanent installation on a truss, watching each cargo carrier and human vehicle arrival
  - Manipulator pointing and machine vision
- **Future Systems Will Benefit from Key System Maturation Efforts**
  - ISS Capability Verification and Enhancement
  - Robotic Servicing Demonstration
  - Teleoperations Support
  - Flight Testing with Noncooperative Targets



Backup



12° Tx FOI

20° Tx FOI

20° Rx FOV

30° X 40° Rx FOV